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[54] **METHOD FOR HYDRAULIC GAS COMPRESSOR**

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Related U.S. Application Data

[60] Division of Ser. No. 309,273, Sep. 20, 1994, which is a continuation-in-part of Ser. No. 258,813, Jun. 13, 1994, abandoned.

[51] **Int. Cl.^{6}** **F04B 41/06**; F15B 13/07

[52] **U.S. Cl.** **417/53**; 417/7; 417/533; 417/102; 222/3

[58] **Field of Search** 417/2, 3, 4, 5, 417/6, 7, 8, 53, 102, 533; 222/3, 254, 265, 275

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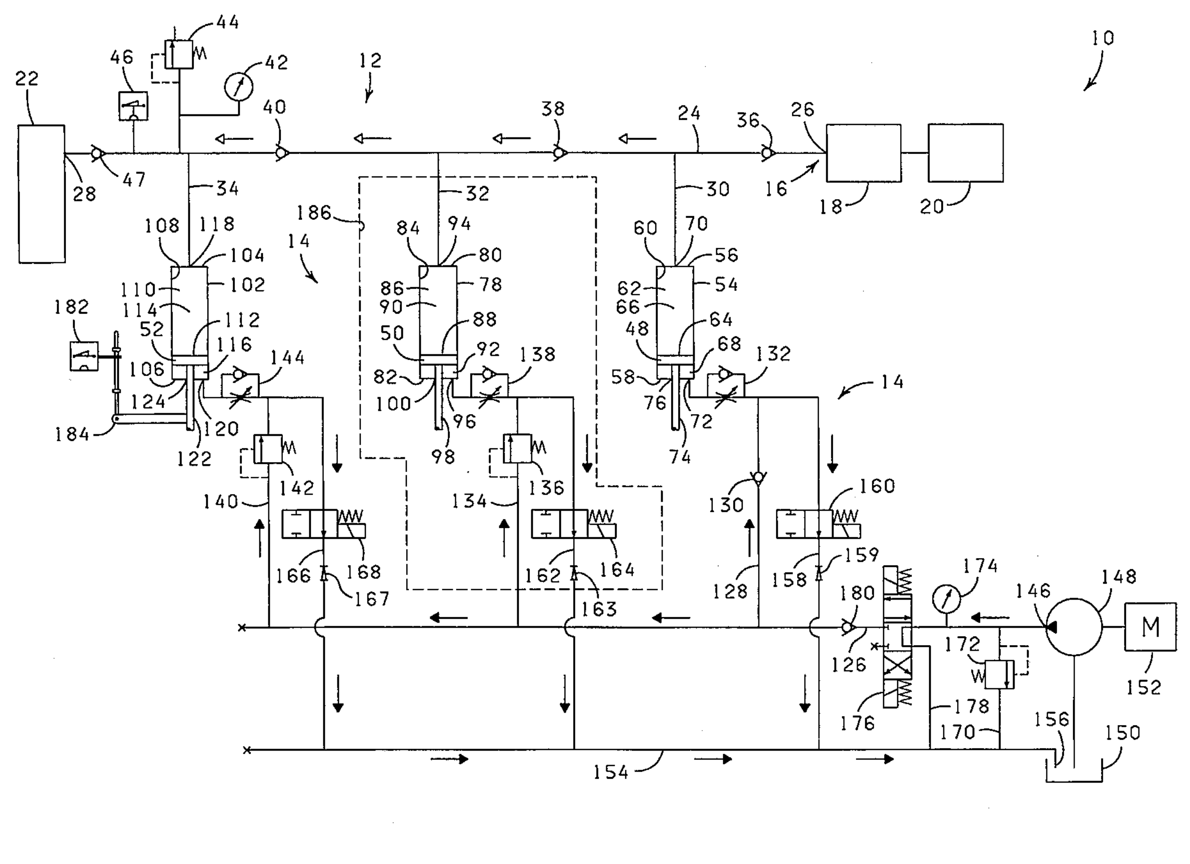
[57] **ABSTRACT**

A gas compressor with at least three hydraulic cylinders is connected to a source of natural gas by a gas line. The gas line can also be removably attached to a storage tank. A hydraulic system is also connected to the cylinders. The compressor additionally includes pressure controls which allow the pistons in the hydraulic cylinders to complete the compression stroke in a staged manner. The cylinders are thereby sequentially emptied of gas. Gas at a sufficient initial pressure, entering the cylinders at the completion of the compression cycle, drives the return stroke of the pistons. A pressure switch controls the pressure level of the compressed gas, and aborts the compression cycle when a predetermined pressure in the storage tank has been reached. If the initial pressure of the natural gas from the gas source is insufficient, a low compression one stage compressor is connected to the gas line upstream of the gas compressor to pressurize the natural gas to sufficient initial pressure prior to introducing the gas into the gas compressor. A pressure distribution assembly having a pressure relief cylinder can also be attached to one or more of the hydraulic cylinders.

6 Claims, 3 Drawing Sheets



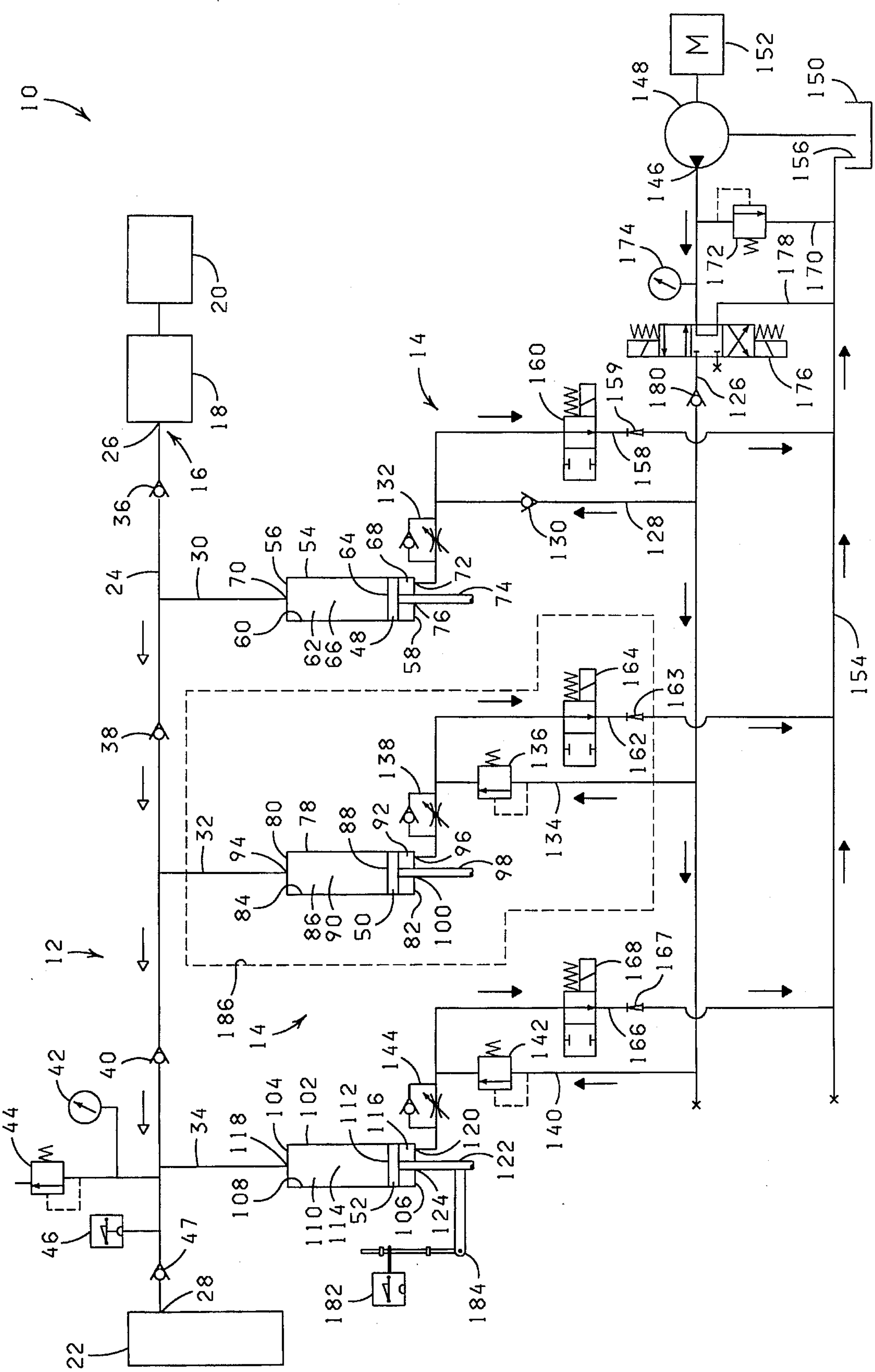


FIG. 1

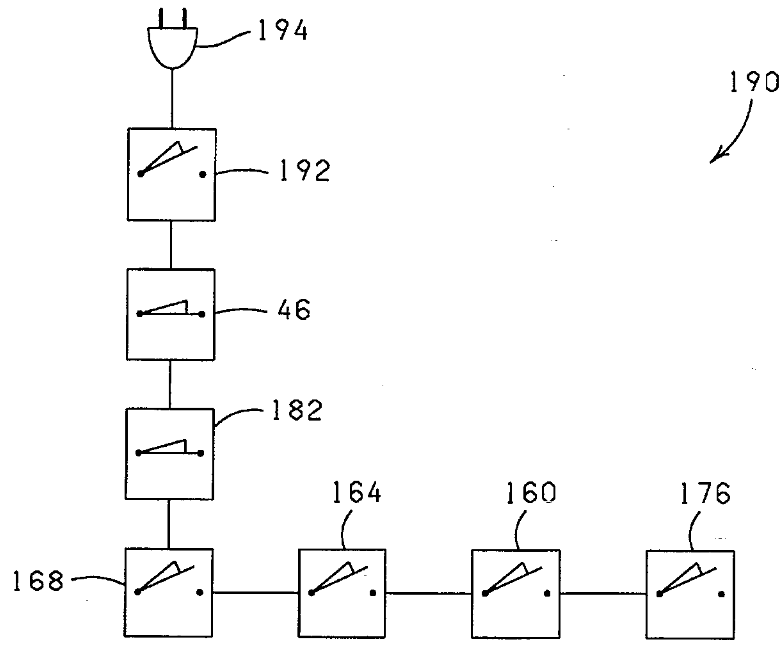

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FIG. 2

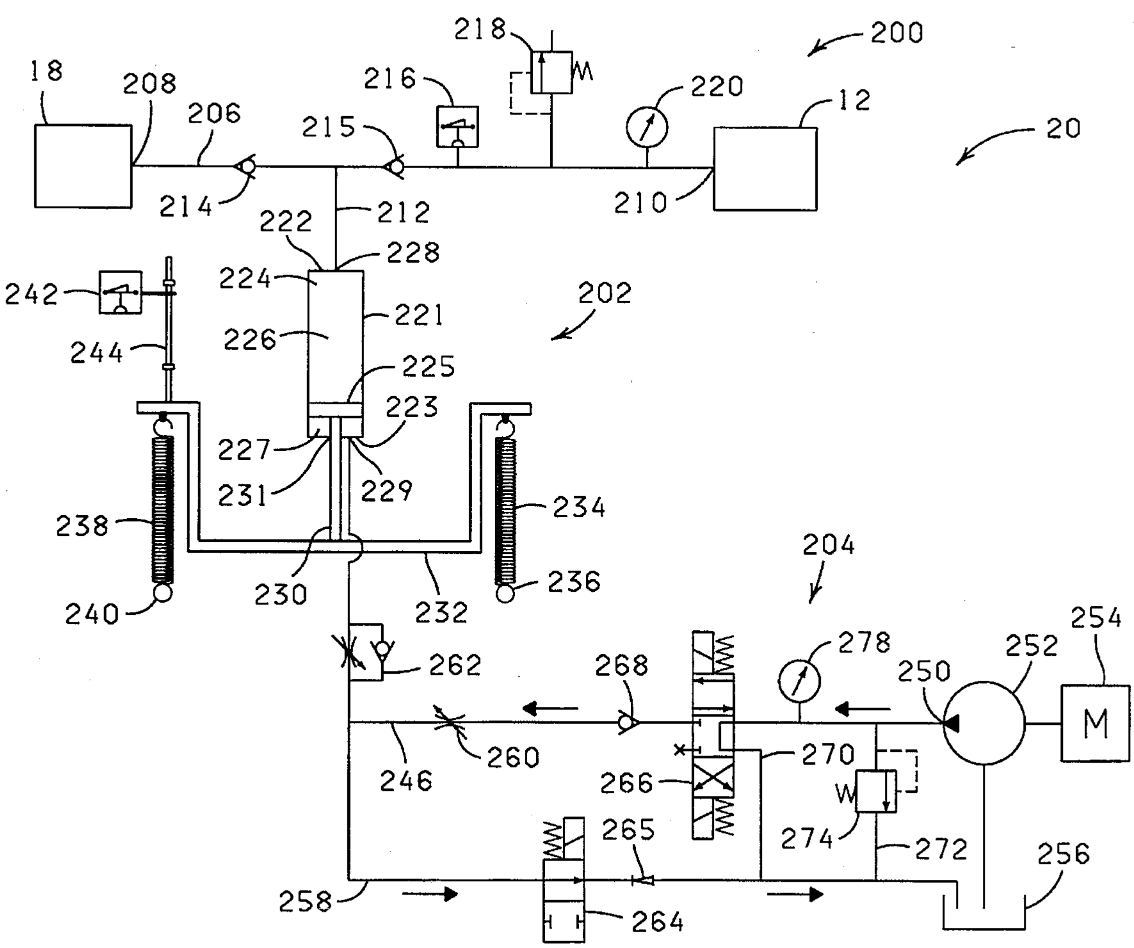
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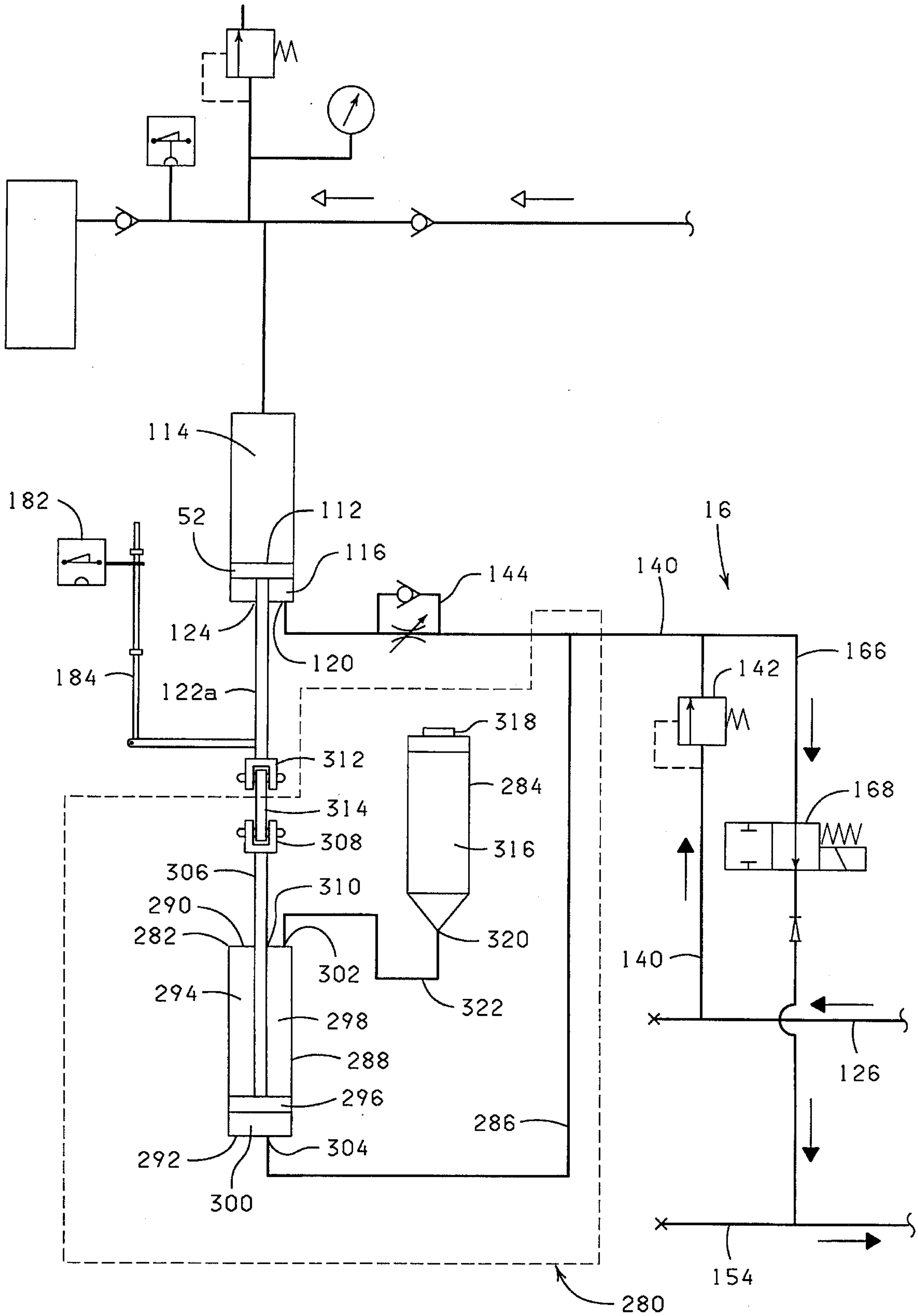
FIG. 3



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308
316
306
310
290
282
320
302
140
294
322
298
126
288
296
286
304
292
300
154
280

FIG. 4

METHOD FOR HYDRAULIC GAS COMPRESSOR

CROSS REFERENCE TO RELATED APPLICATION

This is a divisional of application Ser. No. 08/309,273 filed on Sep. 20, 1994, which is a continuation-in-part of U.S. Ser. No. 08/258,813, filed on Jun. 13, 1994, now abandoned.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to gas compressors, and more particularly, but not by way of limitation, to multi-stage hydraulic compressors for compressing flammable gases, such as natural gas.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic, diagrammatic view of a gas compressor constructed in accordance with the present invention.

FIG. **2** is a schematic, diagrammatic view of an electrical circuit of the gas compressor of FIG. **1**.

FIG. **3** is a schematic, diagrammatic view of a gas feed assembly for use with the gas compressor of FIG. **1**.

FIG. **4** is a partial diagrammatic, schematic view of the gas compressor of FIG. **1**, having a pressure distribution assembly.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Shown in FIG. **1** is a preferred embodiment of a hydraulic gas compressor constructed in accordance with the present invention and identified generally by the reference numeral **10**. The compressor **10** includes a gas transfer assembly **12**, a compression assembly **14**, and a hydraulic assembly **16**. The gas transfer assembly **12** is connected to the compression assembly **14**, and the hydraulic assembly **16** is additionally connected to the compression assembly **14**.

Gas is transported to the compression assembly **14** by way of the gas transfer assembly **12**. The gas is compressed in the compression assembly **14** and compressed gas is transported from the compression assembly **14** by the gas transport assembly **12**. The hydraulic assembly **16** transmits pressure via hydraulic fluid to the gas compression assembly **14**, which enables the gas compression assembly **14** to compress the gas.

The gas transfer assembly **12** is connected at an upstream end **16** to a gas feed assembly **18** which is in turn connected to a natural gas source **20**. The gas feed assembly **18** supplies gas to the gas transfer assembly **12** at an initially sufficient pressure of about forty to one hundred pounds p.s.i. and preferably of about eighty to one hundred pounds p.s.i. If the pressure of the gas at the natural gas source **20** is initially sufficient, the gas feed assembly **18** is omitted and the upstream end **16** of the gas transfer assembly **12** is connected directly to the natural gas source **20**.

The gas transfer assembly **12** is also releasably connected in a conventional manner to a storage cylinder **22**, which receives the compressed gas from the gas transfer assembly **12**. In preferred embodiments of the invention, the storage cylinder **22** is onboard a vehicle (not shown) and is adapted to store compressed natural gas as fuel.

The gas transfer assembly **12** includes a gas line **24** extending from the upstream end **16** to the downstream end **20** of the gas transfer assembly **12**. The gas line **24** is connected at a first end **26** to the gas feed assembly **20**. The gas line **24** is also releasably connected at a second end **28** to the storage cylinder **22**.

The gas line **24** is connected to the compression assembly **14** by way of a first conduit **30**, a second conduit **32** and a third conduit **34**. A check valve **36** is interposed in the gas line **24** between the first end **26** of the gas line **24** and the first conduit **30**. A check valve **38** is additionally interposed in the gas line **24** between the first conduit **30** and the second conduit **32**. A check valve **40** is further interposed in the gas line **24** between the second conduit **32** and the third conduit **34**. The check valves **36**, **38** and **40** permit the flow of gas through the gas line **24** from the upstream end **16** of the gas transfer assembly **12** to the downstream end **20** of the gas transfer assembly **12**, while generally restricting the flow of gas through the gas line **24** from the downstream end **20** to the upstream end **16** of the gas transfer assembly **12**.

A pressure gauge **42** and a relief valve **44** are interposed in the gas line **24** generally between the third conduit **34** and the second end **28** of the gas line **24**. The relief valve **44** is set at a predetermined relief pressure. If the pressure in the gas line **24** increases beyond the predetermined relief pressure for any reason, the relief valve **44** opens, allowing pressurized gas within the gas line **24** to escape to the atmosphere or into a vent tank (not shown).

A pressure switch **46** and a check valve **47** are interposed in the gas line **24** between the relief valve **44** and the second end **28** of the gas line **24**. The pressure switch **46** is set to a predetermined switch pressure. The pressure switch **46** opens if the pressure in the gas line **24** exceeds the predetermined switch pressure. Opening the pressure switch **46** stops the compression cycle, as will be explained below. Gas is thereby prevented from flowing into the storage cylinder **22** through the second end **28** of the gas line **24**.

If the pressure in the gas line **24** falls below the predetermined switch pressure, the pressure switch **46** closes, starting the compression cycle and allowing gas to flow into the storage cylinder **22**. The check valve **47** prevents the backflow of gas from the storage cylinder **22** to the gas line **24**.

It has been found satisfactory to construct the gas line **24** of pressure resistant ⅜" diameter pipe rated at about 5000 p.s.i., whereas the first, second and third conduits **30**, **32** and **34** are constructed of pressure resistant ¼" diameter pipe rated at about 5000 p.s.i. Sections of pressure resistant pipe are threaded to connect to the hardware discussed above and to the compression assembly **14**. Although pressure resistant pipe has been used herein, in other embodiments of the gas compressor **10**, the gas line **24** and the first, second and third conduits **30**, **32** and **34** can be constructed of other materials known to the art, such as pressure hose or hydraulic line.

The compression assembly **14** is connected to the gas transfer assembly **12** by way of the first, second and third conduits **30**, **32** and **34** in order to permit gas to pass into and out of the compression assembly **14**. While the compression assembly **14** may include three or more hydraulic cylinders, the embodiment of the compression assembly **14** shown in FIG. **1** includes a first hydraulic cylinder **48**, a second hydraulic cylinder **50** and a third hydraulic cylinder **52**. The first, second and third hydraulic cylinders **48**, **50** and **52** are generally vertically oriented, as shown in FIG. **1**.

The first hydraulic cylinder **48** of the compression assembly **14** includes a closed sidewall **54** having an upper end **56**, a lower end **58** and an interior surface **60**. The interior surface **60** defines an interior cavity **62** having a piston **64** slidingly contained therein. The piston **64** is sized and constructed to provide a seal between the piston **64** and the interior surface **60** of the closed sidewall **54** of the first hydraulic cylinder **48**. The interior cavity **62** and the piston **64** further define a gas area **66** and a fluid area **68**.

The first hydraulic cylinder **48** also is provided with an upper port **70** formed through the upper end **56** of the closed sidewall **54**. A lower port **72** is formed through the lower end **58** of the closed sidewall **54** of the first hydraulic cylinder **48**. The first hydraulic cylinder **48** further includes a piston rod **74** movably attached to the piston **64** and extending through the lower end **58** of the closed sidewall **54** via an aperture **76**.

The second hydraulic cylinder **50** is constructed in a similar manner to that of the first hydraulic cylinder **48**. The second hydraulic cylinder **50** of the compression assembly **14** includes a closed sidewall **78** having an upper end **80**, a lower end **82** and an interior surface **84**. The interior surface **84** defines an interior cavity **86** having a piston **88** slidingly contained therein. The piston **88** is sized and constructed to provide a seal between the piston **88** and the interior surface **84** of the closed sidewall **78** of the second hydraulic cylinder **50**. The interior cavity **86** and the piston **88** further define a gas area **90** and a fluid area **92**.

The second hydraulic cylinder **50** also is provided with an upper port **94** formed through the upper end **80** of the closed sidewall **78**. A lower port **96** is formed through the lower end **82** of the closed sidewall **78** of the second hydraulic cylinder **50**. The second hydraulic cylinder **50** further includes a piston rod **98** movably attached to the piston **88** and extending through the lower end **82** of the closed sidewall **78** via an aperture **100**.

The third hydraulic cylinder **52** is constructed similarly to the first and second hydraulic cylinders **48** and **50**. The third hydraulic cylinder **52** of the compression assembly **14** includes a closed sidewall **102** having an upper end **104**, a lower end **106** and an interior surface **108**. The interior surface **108** defines an interior cavity **110** having a piston **112** slidingly contained therein. The piston **112** is sized and constructed to provide a seal between the piston **112** and the interior surface **108** of the closed sidewall **102** of the third hydraulic cylinder **52**. The interior cavity **110** and the piston **112** further define a gas area **114** and a fluid area **116**.

The third hydraulic cylinder **52** also is provided with an upper port **118** formed through the upper end **104** of the closed sidewall **102**. A lower port **120** is formed through the lower end **106** of the closed sidewall **102** of the third hydraulic cylinder **52**. The third hydraulic cylinder **52** further includes a piston rod **122** movably attached to the piston **112** and extending through the lower end **106** of the closed sidewall **102** via an aperture **124**.

Different types and sizes of hydraulic cylinders may be used as the first, second and third hydraulic cylinders **48, 50** and **52** of the compression assembly **14**. However, desirable results have been achieved where the first, second and third hydraulic cylinders **48, 50** and **52** are Cross Corporation 3½" diameter welded hydraulic cylinders rated at three thousand p.s.i.

The compression assembly **14** is connected to the hydraulic assembly **16** by way of the lower ports **72, 96** and **120** of the first, second and third hydraulic cylinders **48, 50** and **52**. The hydraulic assembly **16** supplies hydraulic fluid sequentially to the first, second and third hydraulic cylinders **48, 50** and **52**. The hydraulic assembly also permits the hydraulic fluid to drain sequentially from the first, second and third hydraulic cylinders **48, 50** and **52**.

The hydraulic assembly **16** includes a pressure line **126**. The pressure line **126** is connected to the lower port **72** of the first hydraulic cylinder **48** by way of a first receiving line **128**. A check valve **130** is interposed in the first receiving line **128**. A flow control valve **132** is also interposed in the first receiving line **128** between the check valve **130** and the lower port **72** of the first hydraulic cylinder **48**.

The pressure line **126** further is connected to the lower port **96** of the second hydraulic cylinder **50** by way of a second receiving line **134**. A relief valve **136** is interposed in the second receiving line **134**. A flow control valve **138** is additionally interposed in the receiving line **134** between the line relief valve **136** and the second lower port **96** of the second hydraulic cylinder **50**.

The pressure line **126** still further is connected to the lower port **120** of the third hydraulic cylinder **52** by way of a third receiving line **140**. A relief valve **142** is interposed in the third receiving line **140**, and a flow control valve **144** is also interposed in the third receiving line **140** between the relief valve **142** and the lower port **120** of the third hydraulic cylinder **52**.

The pressure line **126** is also connected at an end **146** to a pump **148**, which is in turn connected to a reservoir **150**. The pump **148** is positioned to draw hydraulic fluid from the reservoir **150** and pump the hydraulic fluid under pressure through the pressure line **126**, and through the first, second and third receiving lines **128, 134** and **140** into the fluid areas **68, 92** and **116** of the first, second and third hydraulic cylinders **48, 50** and **52**.

Any commercially available pump capable of delivering hydraulic fluid under sufficient pressure can be employed as the pump **148**. For example, desirable results have been obtained wherein the pump **148** is a J. S. Barnes Corporation High Pressure Gear Pump, No. 736049R. The pump **148** can be powered by any convenient method, such as by use of an electric motor **152**. In this embodiment, the electric motor **152** is a five horsepower AC electric motor, geared to provide the proper drive.

The pressure line **126** and the first, second and third receiving lines **128, 134** and **140** can be constructed of any material and in any conventional manner known to the art. For example, pressure hose or hydraulic line may be used. In this embodiment of the invention, it has been found satisfactory to use ½ diameter pressure resistant pipe rated at 5000 p.s.i.

The hydraulic assembly **16** also includes a return line **154** with an end **156** connected to the reservoir **150**. The return line **154** receives hydraulic fluid which drains from the fluid areas **68, 92** and **116** of the first, second and third hydraulic cylinders **48, 50** and **52**. The return line **154** returns the received hydraulic fluid to the reservoir **150**, where the fluid is available to be returned by the pump **148** to the pressure line **126**. In this embodiment of the invention, the return line has been constructed satisfactorily of 1" diameter steel pipe.

The return line **154** is connected to a first outflow line **158**, a second outflow line **162**, and a third outflow line **166**. The first, second and third outflow lines **158, 162** and **166** provide a return path to the return line **154** for hydraulic fluid drained from the first, second and third hydraulic cylinders **48, 50** and **52**.

The first outflow line **158** is connected to the first receiving line **128** between the check valve **130** and the flow control valve **132**. The first outflow line **158** has a swedge **159** and a solenoid valve **160** interposed therein and is further connected to the return line **154**.

The second outflow line **162** is connected to the second receiving line **134** between the relief valve **136** and the flow control valve **138**. The second outflow line **162** has a swedge **163** and a solenoid valve **164** interposed therein and is further connected to the return line **154**.

The third outflow line **166** is connected to the third receiving line **140** between the relief valve **142** and the flow control valve **144**. The third outflow line **166** has a swedge **167** and a solenoid valve **168** interposed therein and is further connected to the return line **154**. In this embodiment of the invention, it has been found satisfactory to use a Hydraforce, Inc. Solenoid, Model No. 6316115, in combination with a Sun Corporation Valve, Model No. 7026630, for the solenoid valves **160**, **164** and **168**.

In this embodiment of the invention, sections of the first, second and third outflow lines **158**, **162** and **166** are constructed of ½ diameter pressure resistant pipe, rated at about 5000 p.s.i. Additional sections of the first, second and third outflow lines **158**, **162** and **166** between the swedges **159**, **163** and **167** and the receiving line **154** are constructed of 1" diameter steel pipe.

A relief line **170** having a relief valve **172** is connected to the pressure line **126** and to the return line **154**. A pressure gauge **174** is interposed in the pressure line **126** between a four way solenoid valve **176** and the connection of the pressure line **126** to the relief line **170**. The four way solenoid valve **176** is additionally connected to a bypass line **178**, which is further connected to the return line **154**. A check valve **180** is interposed in the pressure line **126** between the four way solenoid valve **176** and the connection of the pressure line **126** with the first receiving line **128**. An example of the four way solenoid valve **176** that has proved satisfactory for use in this embodiment of the gas compressor **10** is Parker Corp. Valve Model No. DIVW8CNYC 70 with a tandem center section.

As shown in FIG. **1**, the hydraulic assembly **16** additionally includes a limit switch **182**. The limit switch **182** is connected to a control rod **184**; and the control rod **184** is connected to the piston rod **122** of the third hydraulic cylinder **52**.

Turning to FIG. **2**, an electrical circuit **190** is shown which is used with the embodiment of the invention shown in FIG. **1**. The circuit **190** includes a switch **192** connected to an electric current source **194**. The switch **192** is further connected in series to the pressure switch **46**, the limit switch **182**, the solenoid valves **168**, **164** and **160**, and the four way solenoid valve **176**. Electric current to the solenoid valves **168**, **164** and **160** and to the four way solenoid valve **176** can be controlled by the pressure switch **46** or the limit switch **182**.

As will be appreciated, the electrical and mechanical hardware from which the gas compressor **10** is constructed can be changed in accordance with known principles of hydraulic design. For example, the sizes of the first, second and third hydraulic cylinders **48**, **50** and **52** can be varied for particular applications. The size of the first, second and third hydraulic cylinders **48**, **50** and **52** used in the embodiment of the gas compressor **10** shown in FIG. **1** may prove suitable for a home gas compression station.

For different applications, larger cylinders can be used to give a greater output of compressed gas to the storage cylinder **22**. Additionally, explosion proof hardware can be substituted for the electrical hardware, such as the solenoid valves **160**, **164**, **168** and **176**. Alternately, the electrical hardware can be isolated behind a barrier.

The compressor **10** can be modified to include additional compression stages, for example by including two or more second hydraulic cylinders **50**. The second hydraulic cylinder **50** and its associated hardware can be further described as an expansion module and given the additional reference numeral **186**, as shown in FIG. **1**. By connecting additional expansion modules **186** to the gas transfer assembly **12** and the hydraulic assembly **16**, a gas compressor **10** can be constructed having as many compression stages as desired for a given application.

Additionally, FIG. **1** shows that one port of the four way solenoid valve **176** is plugged. By connecting a second pressure line **126** to the four way solenoid valve **176** and by connecting the unused solenoid of the four way solenoid valve **176** to a switchable electric circuit, a second hydraulic assembly **16** attached to a second gas compressor **10** can be connected to the gas compressor **10**. The second gas compressor **10** can serve as an alternate or backup compressor for the gas compressor **10**.

As explained below gas from the natural gas source **20** preferably will have an initial pressure from about forty to one hundred p.s.i and preferably from about eighty to one hundred p.s.i. If the initial pressure of the gas at the natural gas source **20** is insufficient, the gas feed assembly **18** can be interposed in the gas line **24** between the gas line **24** and the natural gas source **20** to raise the gas pressure to a sufficient level.

The gas feed assembly **18** shown in FIG. **3** comprises a gas transfer assembly **200** connected to a compression assembly **202** and a hydraulic assembly **204** connected to the compression assembly **202**. The gas transfer assembly **200** is connected to the natural gas source **20** the gas transfer assembly **12** of the gas compressor **10**.

The gas transfer assembly **200** of the gas feed assembly **18** transports gas from the natural gas source **20** to the compression assembly **202** and from the compression assembly **202** of the gas feed assembly **18** to the gas transfer assembly **12** of the gas compressor **10**.

The compression assembly **202** of the gas feed assembly **18** accepts gas from the natural gas source **20**, compresses the gas, and delivers the gas, via the gas transfer assembly **200** of the gas feed assembly **20** to the gas transfer assembly **12** of the gas compressor **10**. The hydraulic assembly **204** of the gas feed assembly **18** provides hydraulic fluid under pressure to the compression assembly **202** and drains the hydraulic fluid from the compression assembly **202** of the gas feed assembly **20**.

The gas transfer assembly **200** of the gas feed assembly **18** includes a gas line **206**. The gas line **206** of the gas transfer assembly **200** has a first or upstream end **208**, which is connected to the natural gas source **20**, and a second or downstream end **210**, which is connected to the gas transfer assembly **12** of the gas compressor **10**. A conduit **212** connects the gas line **206** with the compression assembly **202**, as will be explained below. The gas transfer assembly **200** of the gas feed assembly **18** also includes a check valve **214**, located between the conduit **212** and the upstream end **208** of the gas line **206**. A check valve **215**, a pressure switch **216**, a relief valve **218**, and a pressure gauge **220** are interposed in the gas line **206** between the conduit **212** and the downstream end **210** of the gas line **206** of the gas transfer assembly **200**.

The compression assembly **202** of the gas feed assembly **18** includes a hydraulic cylinder **221**. The hydraulic cylinder

221 may be constructed similarly to the first, second and third hydraulic cylinders **48**, **50** and **52** of the gas compressor **10**, or the hydraulic cylinder **200** may be constructed in any other suitable manner.

The hydraulic cylinder **221** of the compression assembly **202** has an upper end **222**, a lower end **223** and an interior cavity **224** extending therebetween. A piston **225** is slidably disposed within the interior cavity **224** of the hydraulic cylinder **221** substantially as shown. The piston **225** divides the interior cavity **224** into a gas area **226** and a fluid area **227**. An upper port **228** is formed in the hydraulic cylinder **221** allowing communication with the gas area **226** of the interior cavity **224** of the hydraulic cylinder **221**. A lower port **229** is formed in the hydraulic cylinder **221**, allowing communication with the fluid area **227** of the interior cavity **224** of the hydraulic cylinder **221**.

The hydraulic cylinder **221** additionally includes a piston rod **230** movably attached to the piston **225** and extending through the lower end **223** of the hydraulic cylinder **221** via an aperture **231**. A piston rod frame **232** is attached to the piston rod **230**. A first spring **234** having a tension adjustment bolt **236** and a second spring **238** having a tension adjustment bolt **240** are also attached to the piston rod frame **232**.

The compression assembly **202** of the gas feed assembly **20** additionally includes a limit switch **242** and a limit switch control rod **244**. The limit switch control rod is attached to the piston rod frame **232**, and the limit switch **242** is movably attached to the limit switch control rod **244**.

The hydraulic assembly **204** of the gas feed assembly **20** includes a pressure line **246** attached to the lower end **223** of the hydraulic cylinder **221** via the lower port **229** so that fluid communication is established between the pressure line **246** and the fluid area **227** of the hydraulic cylinder **221**. The pressure line **246** of the hydraulic assembly **204** additionally has an end **250** attached to a pump **252** which is in turn attached to a motor **254**. The pump **252** is positioned to draw hydraulic fluid from a reservoir **256**.

The hydraulic assembly **204** additionally includes a return line **258**. The return line **258** is connected to the pressure line **246** between a first fluid control valve **260** and a second fluid control valve **262**. A solenoid valve **264** is interposed in the return line **258** of the hydraulic assembly **204**.

A four way solenoid valve **266** is interposed in the pressure line **246** of the hydraulic assembly **204** between a check valve **268** and the pump **252**. A bypass line **270** is connected to the four way solenoid valve **266** and further connected to the return line **258**. Additionally, the hydraulic assembly **204** has a relief line **272** connected to the pressure line **246** between the four way solenoid valve **266** and the pump **250**. The relief line **272** is further connected to the return line **258** of the hydraulic assembly **204**, and a relief valve **274** is interposed in the relief line **272** of the hydraulic assembly **204**. A pressure gauge **278** is interposed in the pressure line **246** between the four way solenoid valve **266** and the relief line **272** of the hydraulic assembly **204**.

The gas feed assembly **18** includes an electrical circuit (not shown). The electrical circuit of the gas feed assembly **18** includes a switch serially connected to the limit switch **242**, the pressure switch **216**, the solenoid valve **264** and the four way solenoid valve **266**. As shown in FIG. **3**, the solenoid valve **264** is open and the four way solenoid valve **266** is closed in the "open circuit" position. In the "open circuit" position the solenoid valve **264** is deemed herein to be open, and the four way solenoid valve **266** is deemed herein to be closed.

In operation gas from the natural gas source **20**, which ordinarily will be at a pressure of approximately two to five p.s.i., enters the gas area **226** of the interior cavity **224** of the hydraulic cylinder **221** of the gas feed assembly **18**. The first and second springs **234** and **238** connected to the piston rod frame **232** operate to hold the piston **225** in an armed position near a bottom end of the hydraulic cylinder **221**. Gas is thereby allowed to enter the gas area **226**. When the electric circuit of the gas feed assembly **18** is completed by closing the switch, the four way solenoid valve **266** allows hydraulic fluid to pass along the length of the pressure line **246** and the solenoid valve **264** closes, thereby prohibiting hydraulic fluid from flowing along the return line **258**. Hydraulic fluid is pulled from the reservoir **256** by the pump **252** and transmitted under pressure along the pressure line **246** of the hydraulic assembly **204**.

The rate of flow of hydraulic fluid along the pressure line **246** can be regulated as desired by the flow control valve **260**. Hydraulic fluid enters the fluid area **227** of the hydraulic cylinder **221** via the lower port **229** of the hydraulic cylinder **221**. The pressure of the hydraulic fluid on the piston **225** causes the piston **225** to rise, thereby compressing the gas contained in the gas area **226** of the interior cavity **224** of the hydraulic cylinder **221**. The compressed gas exits the hydraulic cylinder **221** via the upper port **228** and the conduit **212** and is directed into the gas line **206** of the gas transfer assembly **200**. The check valve **214** prevents the compressed gas from flowing toward the upstream end **208** of the gas line **206** of the gas transfer assembly **200**.

When the piston **225** approaches the top of the hydraulic cylinder **221**, the limit switch control rod **244** attached to the piston rod frame **232** opens the limit switch **242**, thereby opening the circuit relative to the solenoid valve **264** and the four way solenoid valve **266**. The solenoid valve **266** closes as shown in FIG. **3**, routing hydraulic fluid pumped by the pump **250** via the bypass line **270** to the return line **258** and back to the reservoir **256** of the hydraulic assembly **204**.

Additionally, the hydraulic fluid is forced from the cylinder **221** at least partially by gravity and partially by the downward pressure applied to the piston **225** by the first spring **234** and second spring **238** acting on the piston rod frame **232** which is attached to the piston rod **230** which is in turn movably attached to the piston **225** of the hydraulic cylinder **221**. As the piston **225** moves downward, gas is drawn into the hydraulic cylinder **221** via the conduit **212** of the gas line **206**.

The fluid exits the cylinder **221** via the lower port **229** and enters the receiving line **258** via the flow control valve **262**. The flow control valve **262** is adjusted to prevent the piston **225** from slamming against the lower end of the hydraulic cylinder **221** as the piston **225** moves to the armed position. Hydraulic fluid in the return line **258** flows through the solenoid valve **264** to the reservoir **256**.

As before mentioned, the gas transfer assembly **200** of the gas feed assembly **200** includes a pressure switch **216**. The pressure switch **216** is set for a range of gas pressures, preferably from about eighty to about one hundred pounds p.s.i. If the gas pressure exceeds one hundred pounds p.s.i. the pressure switch **216** opens, thereby opening the electrical circuit and causing solenoid valves **264** and **266** to move to the opened and closed positions, respectively. If the pressure in the gas line **206** rises beyond a predetermined level for any reason the relief valve **218** opens, allowing gas to vent to the atmosphere or to a vent tank (not shown). If the pressure falls below a predetermined low pressure, the pressure switch **216** closes, thereby closing the electrical circuit and causing solenoid valves **264** and **266** to move to the closed and open position, respectively, causing another compression cycle to start.

Similarly, if the pressure in the pressure line **246** rises above a predetermined pressure for any reason, the relief valve **274** opens, thereby causing hydraulic fluid to be shunted from the pump to the return line **258** via the relief line **272** of the hydraulic assembly **204**.

The gas feed assembly **18** can be constructed using the same hardware used in the construction of the gas compressor **10**. Other satisfactory hardware, as known in the art, may also be used. Additionally, the gas feed assembly **18** can be any suitable commercially available single stage compressor which is preferably explosion proof.

Returning to FIG. **1**, in operation the gas compressor **10** initially is in a non-operative mode (switch **192** shown in FIG. **2** is in the open position, thereby causing the circuit **190** to be open). With the circuit **190** open, the four way solenoid valve **176** connects a section of the pressure line **126** with the bypass line **178**.

If power is applied to the pump **26** when the circuit **190** is open, hydraulic fluid is drawn from the reservoir **150** by the pump **148** and pumped into a section of the pressure line **126**. However, the fluid is shunted to the return line **154** via the bypass line **178** and returned to the reservoir **150**. Additionally, if the pressure in the above described section of the pressure line **126**, as indicated by the pressure gauge **174**, exceeds a predetermined point for any reason, the relief valve **172** opens, shunting the hydraulic fluid via relief line **170** to the return line **154** and thereafter to the reservoir **150**.

With the circuit **190** open, solenoid valves **160**, **164** and **168** are open, as shown in FIG. **1**.

With power to the gas compressor **10** disabled, gas ordinarily is present in the gas transfer assembly **12**. The gas fills the gas areas **66**, **90** and **114** of the first, second and third hydraulic cylinders **48**, **50** and **52**, and additionally fills the storage cylinder **22**. With a pressure from about forty to about one hundred p.s.i., the gas forces the pistons **64**, **88** and **112** downward in the first, second and third hydraulic cylinders **48**, **50** and **52**.

Substantially all of the hydraulic fluid present in the fluid area **68** of the first hydraulic cylinder **48**, in the fluid area **92** of the second hydraulic cylinder **50** and in the fluid area **116** of the third hydraulic cylinder **52** is at least partially forced out the fluid areas **68**, **92** and **116** by the gas pressure on the pistons **64**, **88** and **112**.

The fluid in the first hydraulic cylinder **48** drains via the lower port **72**, the fluid control valve **132**, the first outflow line **158** and the first open solenoid valve **160** to the return line **154** and thereafter into the reservoir **150**. The check valve **130** prevents the draining fluid from passing through the first receiving line **128**.

The fluid in the second hydraulic cylinder **50** drains via the lower port **96**, the fluid control valve **138**, the second outflow line **162** and the open solenoid valve **164** to the return line **154** and thereafter into the reservoir **150**. The relief valve **136** prevents the draining fluid from passing through the second receiving line **134**.

Similarly the fluid in the third hydraulic cylinder **52** drains via the lower port **120**, the fluid control valve **144**, the third outflow line **166** and the open solenoid valve **168** to the return line **154** and thereafter into the reservoir **150**. The relief valve **142** prevents the draining fluid from passing through the third receiving line **140**.

The flow control valves **132**, **138** and **144** are set at predetermined flow adjustments. The flow adjustments are chosen so that the rate of travel of the piston **64** within the first hydraulic cylinder **48** and of the piston **88** within the second hydraulic cylinder **50** is greater than the rate of travel of the piston **112** within the third hydraulic cylinder **52**.

The flow adjustments are additionally chosen to cushion the downward movement of the pistons **64**, **88** and **112** to prevent the pistons **64**, **88** and **112** from slamming into the lower ends **58**, **82** and **106** of the interior surfaces **60**, **84** and **108** of the first, second and third hydraulic cylinders **48**, **50** and **52**, due to the gas pressure within the cylinders. The piston rods **74**, **98** and **122** further act to stabilize the movement of the pistons **64**, **88** and **112** within the interior cavities **62**, **86** and **110** of the first, second and third hydraulic cylinders **48**, **50** and **52**.

When the pistons **64**, **88** and **112** have traveled to a position generally adjacent the lower ends **58**, **82** and **106** of the first, second and third hydraulic cylinders **48**, **50**, and **52**, the pistons **64**, **88** and **112** are considered to be in the armed position.

When the circuit **190** of the gas compressor **10** is closed, thereby starting a compression cycle, the solenoid valves **160**, **164** and **168** close. Hydraulic fluid is thereby prevented from passing through the first, second and third outflow lines **158**, **162** and **166**. The four-way solenoid valve **176** opens, permitting hydraulic fluid to flow through the pressure line **126** to the first, second and third receiving lines **128**, **134** and **140**.

The pressure of the hydraulic fluid in the pressure line **126** opens the check valve **130** which allows hydraulic fluid to enter the fluid area **68** within the first hydraulic cylinder **48** via the receiving line **128**. The pressure of the hydraulic fluid on the piston **64** causes the piston **64** to rise, compressing the gas within the gas area **66** of the first hydraulic cylinder **48**. The gas is forced into the gas areas **90** and **114** of the second and third hydraulic cylinders **50** and **52**. Gas is also forced into the connected storage tank **22**. The check valves **36**, **38** and **40** prevent the pressurized gas from passing to the first end **26** of the gas line **24**.

The relief valve **136** in the receiving line **134** has been set to open at a predetermined pressure which is slightly greater than the pressure in the pressure line **126** when the piston **44** reaches the upward end **56** of the first hydraulic cylinder **48**. The pressure at the predetermined pressure opens the relief valve **136**, and fluid enters the fluid area **92** within the second hydraulic cylinder **50** via the second receiving line **134**. The pressure of the hydraulic fluid on the piston **88** causes the piston **88** to rise, compressing the gas within the gas area **90** of the second hydraulic cylinder **50**. The gas is forced into the gas area **114** of the third hydraulic cylinder **52**. Gas is also forced into the connected storage cylinder **22**.

In a similar manner the relief valve **142** in the third receiving line **140** has been set to open at a predetermined pressure which is slightly greater than the pressure in the pressure line **126** when the piston **88** reaches the upward end **80** of the second hydraulic cylinder **52**. The pressure at the predetermined pressure opens the relief valve **142**, and fluid enters the fluid area **116** within the third hydraulic cylinder **52** via the third receiving line **140**. The pressure of the hydraulic fluid on the piston **112** causes the piston **112** to rise, compressing the gas within the gas area **114** of the third hydraulic cylinder **52**. The gas is forced into the connected storage cylinder **22**. The check valve **47** prevents the gas within the storage cylinder **22** from flowing toward the first end **26** of the gas line **24**.

The piston rod **122** connected to the piston **112** rises along with the piston **112**. As the piston rod **112** rises, the control rod **184** attached to the piston rod **122** also rises and, at a predetermined position, the control rod **184** opens the limit switch **182**, thereby opening the circuit **190**. Opening the circuit **190** causes the solenoid valves **160**, **164** and **168** to open, as explained above. Fluid is thereby allowed to drain from the first, second and third hydraulic cylinders **48**, **50** and **52**, as previously discussed.

Opening of the limit switch **184** also causes the four way solenoid valve **176** to connect the bypass line **178** to the pressure line **126**. Gas from the gas transfer assembly **12** again enters the gas areas **66**, **90** and **114** of the first, second and third hydraulic cylinders **48**, **50** and **52**. The pressure of the incoming gas forces the pistons **64**, **88** and **112** downward in the interior cavities **62**, **86** and **110** of the first, second and third hydraulic cylinders **48**, **50**, and **52**, having the effect of arming the pistons, as explained above.

The rate of flow of the hydraulic fluid from the first, second and third hydraulic cylinders **48**, **50** and **52** is controlled by the flow control valves **132**, **138** and **144**, as previously explained. By controlling the respective rates of flow, the piston **112** of the third hydraulic cylinder **52** will be the last of the pistons to arm. When the control rod **184** attached to the piston rod **122** of the piston **112** moves downward to a predetermined position, the limit switch **182** is closed by the control rod **184**, thereby closing the circuit **190**. Closing the circuit **190** has the effect of closing the solenoid valves **160**, **164** and **168** and of changing the connections of the four way solenoid valve **176**, causing a second compression cycle to begin.

The gas compressor **10** will perform compression cycles until the switch **192** is opened or until the pressure switch **46** is opened, thereby opening the circuit **190**. The pressure switch **46** is set for a predetermined range of pressure, the pressure being monitored at a position in the gas line **24** about adjacent the pressure switch **46**. When the predetermined pressure range is reached or exceeded, the pressure switch **46** opens, thereby opening the circuit **190** and aborting the compression cycle in progress. It will be appreciated that if electric current to the electric current source **194** fails, the compression cycle similarly will be aborted.

If the pressure falls below the predetermined pressure range of the pressure switch **46**, the pressure switch **46** closes. This has the effect of closing the circuit **190** and of initiating another compression cycle.

The efficiency and utility of the gas compressor **10** may be increased by incorporating into the gas compressor **10** one or more pressure distribution assemblies **280** as schematically illustrated in FIG. **4**. Although the pressure distribution assembly **280** shown in FIG. **4** is connected to the third hydraulic cylinder **52** of the compression assembly **14** of the gas compressor **10**, it is to be understood that pressure distribution assemblies **280** can be connected to any or all of the hydraulic cylinders of the gas compressor **10**.

The pressure distribution assembly **280** accepts a portion of the pressure that would otherwise be applied to the fluid area **116** of the third hydraulic cylinder **52**. The pressure distribution assembly **280** also transfers force obtained from the accepted pressure to the piston **112** of the third hydraulic cylinder **52**, thereby assisting in the compression of gas contained in the gas area **114** of the third hydraulic cylinder **52**.

The pressure distribution assembly **280** includes a relief hydraulic cylinder **282** connected to the third hydraulic cylinder **52**. The pressure distribution assembly **280** also includes a fluid reservoir **284** connected to the relief hydraulic cylinder **282** and a pressure distribution line **286** connected to the relief hydraulic cylinder **282** and further connected to the third receiving line **140**.

The relief hydraulic cylinder **282** of the pressure distribution assembly **280** includes a closed sidewall **288** having an upper end **290** and a lower end **292**. The closed sidewall **288** of the relief hydraulic cylinder **282** defines an interior cavity **294** having a piston **296** slidingly contained therein. The piston **296** is sized and constructed to provide a seal between the piston **296** and an interior surface of the closed sidewall **288** of the relief hydraulic cylinder **282**. The interior cavity **294** and the piston **296** further define an upper fluid area **298** and a lower fluid area **300**.

The relief hydraulic cylinder **282** also is provided with an upper port **302** formed through the upper end **290** of the closed sidewall **288**. A lower port **304** is formed through the lower end **292** of the closed sidewall **288** of the relief hydraulic cylinder **282**. The relief hydraulic cylinder **282** further includes a piston rod **306** having a clevis **308**. The piston rod **306** is movably attached to the piston **296** and extends through the upper end **292** of the closed sidewall **288** via an aperture **310**.

In the embodiment of the gas compressor **10** shown in FIG. **4**, the piston rod **306** of the relief hydraulic cylinder **282** is attached to the piston rod **122***a* of the third hydraulic cylinder **52**. The construction and operation of the piston rod **122***a* is the same as that of the piston rod **122** shown in FIG. **1**; however, a clevis **312** has been attached to a free end of the piston rod **122***a*.

The clevis **312** of the piston rod **122***a* is connected to the clevis **308** of the piston rod **306** of the relief hydraulic cylinder **282** by way of a connection rod **314**. The connection of the piston rod **122***a* and the piston rod **306** forces the piston **112** of the third hydraulic cylinder **52** and the piston **296** of the relief hydraulic cylinder **282** to move in unison.

The pressure distribution assembly **280** also includes a fluid reservoir **284**. The fluid reservoir **284** includes an interior cavity **316** which is at least partially filled with hydraulic fluid. The fluid reservoir also includes a vented cap **318**. The vented cap **318** allows the egress and ingress of air into the interior cavity **316** of the fluid reservoir **284**.

The fluid reservoir **284** includes a port **320** which allows fluid communication with the interior cavity **316** of the fluid reservoir **284**. The interior cavity **316** of the fluid reservoir **284** is connected to the upper fluid area **298** of the relief hydraulic cylinder **282** by way of a fluid transfer line **322**. The fluid transfer line **322** is connected to the port **320** of the fluid reservoir **284** and to the upper port **302** of the relief hydraulic cylinder **282**.

The fluid reservoir **284** is positioned relative to the relief hydraulic cylinder **282** in such a manner that hydraulic fluid can flow, by way of the fluid transfer line **322** and at least partially assisted by gravity, from the interior cavity **316** of the fluid reservoir **284** to the upper fluid area **298** of the relief hydraulic cylinder **282** when the piston **296** approaches an armed position within the interior cavity **294** of the relief hydraulic cylinder **282**, as shown in FIG. **4**.

The pressure distribution assembly **280** additionally includes a pressure distribution line **286**. The pressure distribution line **286** is connected to the third receiving line **140** of the hydraulic assembly **16**. The pressure distribution line **286** is connected to the third receiving line **140** between the relief valve **142** and the flow control valve **144**. The pressure distribution line **286** is further connected to the lower fluid area **300** of the relief hydraulic cylinder **282**. The pressure distribution line **286** permits fluid communication between the third receiving line **140** of the hydraulic assembly **16** and the lower fluid area **300** of the relief hydraulic cylinder **282** of the pressure distribution assembly **280**.

In operation, fluid under pressure in the third receiving line **140** of the hydraulic assembly **16** enters the fluid area **116** of the third hydraulic cylinder **52** and the lower fluid area **300** of the relief hydraulic cylinder **282**, by way of the pressure distribution line **286**. The piston **296** of the relief hydraulic cylinder **282** is forced upward by the pressure of the fluid in the lower fluid area **300**. The piston **112** of the third hydraulic cylinder **52** is also forced upward by the pressure of the fluid in the fluid area **116**.

Force is transferred from the piston **296**, by way of the piston rods **306** and **122***a* to the piston **112** of the third hydraulic cylinder **52**, thereby assisting in the compression of gas within the gas area **114** of the third hydraulic cylinder **52** of the compression assembly **14**. The upward movement of the piston **296** also forces hydraulic fluid from the upper fluid area **298** of the relief hydraulic cylinder **282** and into the interior cavity **316** of the fluid reservoir **284** by way of the fluid transfer line **322**.

When pressure is removed from the third receiving line **140**, hydraulic fluid flows from the fluid area **116** of the third hydraulic cylinder **52** into the third receiving line **140**, at least partially assisted by the pressure of gas entering the gas area **114** of the third hydraulic cylinder **52**, as explained above. When pressure is removed from the third receiving line **140**, hydraulic fluid also flows from the lower fluid area **300** of the relief hydraulic cylinder **282**, at least partially assisted by the weight of hydraulic fluid entering the upper fluid area **298** of the relief hydraulic cylinder **282** by force of gravity. The movement of the interconnected pistons **112** and **296** within the third hydraulic cylinder **52** and the relief hydraulic cylinder **282** respectively, is restricted by the rate of flow of hydraulic fluid through the flow control valve **144**, as explained above.

Changes may be made in the embodiments of the invention described herein or in parts or elements of the embodiments described herein or in the steps or in the sequence of steps of the methods described herein without departing from the spirit and scope of the invention as defined in the following claims.

What is claimed is:

1. A method of compressing gas, comprising the steps of:

connecting a storage tank to an interior cavity of a first hydraulic cylinder, to an interior cavity of at least one second hydraulic cylinder, and to an interior cavity of a third hydraulic cylinder;

connecting the interior cavities of the first, second and third hydraulic cylinders to a gas source supplying a gas;

introducing gas into the interior cavities of the first, second and third hydraulic cylinders and the storage tank;

introducing hydraulic fluid into the interior cavity of the first hydraulic cylinder to compress the gas contained therein and pushing the gas from the interior cavity of the first hydraulic cylinder into the interior cavities of the second and third hydraulic cylinders and into the storage tank, while preventing gas from passing from the interior cavity of the first hydraulic cylinder to the gas source;

introducing hydraulic fluid into the interior cavity of the second hydraulic cylinder to compress the gas contained therein and pushing the gas from the interior cavity of the second hydraulic cylinder into the interior cavity of the third hydraulic cylinder and into the storage tank, while preventing gas from passing from the interior cavity of the second hydraulic cylinder to the interior cavity of the first hydraulic cylinder and to the gas source;

introducing hydraulic fluid into the interior cavity of the third hydraulic cylinder to compress the gas contained therein and pushing the gas from the interior cavity of the third hydraulic cylinder into the storage tank, while preventing gas from passing from the interior cavity of the third hydraulic cylinder to the interior cavities of the first and second hydraulic cylinders and to the gas source; and

draining the hydraulic fluid from the interior cavities of the first, second and third hydraulic cylinders while preventing gas in the storage tank from passing to the interior cavities of the first, second and third hydraulic cylinders and to the gas source.

2. The method of claim **1** wherein the step of draining the hydraulic fluid further comprises controlling the flow of hydraulic fluid from the interior cavities of the first, second and third hydraulic cylinders so that hydraulic fluid is drained from the interior cavities of the first and second hydraulic cylinders prior to draining hydraulic fluid from the interior cavity of the third hydraulic cylinder.

3. The method of claim **1** wherein the step of introducing gas into the interior cavities of the first, second and third hydraulic cylinders further comprises pressurizing the gas to a sufficient initial pressure prior to introduction of the gas into the interior cavities of the first, second and third hydraulic cylinders.

4. The method of claim **1** wherein the steps of:

introducing gas into the interior cavities of the first, second and third hydraulic cylinders and introducing hydraulic fluid into the interior cavities of the first, second and third hydraulic cylinders further comprise completing a compression stage.

5. The method of claim **4** further comprising the step of aborting the compression stage when the pressure in the storage tank reaches a pressure within a predetermined range of pressures.

6. The method of claim **1** further comprising the step of initiating the draining of the hydraulic fluid from the interior cavities of the first, second and third hydraulic cylinders when the hydraulic fluid in the interior cavity of the third hydraulic cylinder reaches a predetermined position.

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UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,622,478

DATED : April 22, 1997

INVENTOR(S) : Elliott et al.

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Column 4, line 49, please delete " ½ " and substitute therefor --½"--.

Column 5, line 20, please delete " ½ " and substitute therefor --½"--.

Signed and Sealed this

Fifteenth Day of July, 1997

Attest:

BRUCE LEHMAN

Attesting Officer *Commissioner of Patents and Trademarks*